WIRES SEGMENTATION IN FLUOROSCOPIC IMAGES DURING CEREBRAL ANEURYSM ENDOVASCULAR INTERVENTION

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ABSTRACT

Endovascular intervention is currently considered the treatment of choice for cerebral aneurysms. Nowadays imaging technology for real-time endovascular tool navigation consists of digital fluoroscopy detectors mounted on C-shaped arms with multiple orientations capability. In theory, a 3D representation of interventional devices (guide wire, coils) can be done using biplane fluoroscopic acquisitions. This approach opens the door to a real 3D road-map guidance of endovascular procedure. However, it is important that the tool be precisely identified during an intervention on the low contrast and low resolution fluoroscopic images. Therefore, a new method for segmenting guide wires and coils on fluoroscopic images is presented. A line enhancement algorithm based on Hessian matrix is applied and line candidates are marked by simple thresholding. Line artifacts are suppressed according to geometric criterion. The remaining line segments are linked when appropriately aligned to assemble continuous tools regardless of crossing from the projection of a planar view. This identifying method is evaluated on *in vivo* fluoroscopic sequences acquired during endovascular interventions on patients with cerebral aneurysm.

Index Terms— Guide wire segmentation, line enhancement, interventional neuroradiology, fluoroscopic image, cerebral aneurysm.

1. INTRODUCTION

Aneurysms are balloon-like out pouchings on the blood vessel wall that occur mostly at branch bifurcations. Blood vessel wall defects combined with high vector velocity changes cause tissues to dilate and expand into aneurysms. Cerebral aneurysm rupture is associated with a high mortality and morbidity rate. In recent years, endovascular treatment has gradually replaced surgical clipping in the management of cerebral aneurysms [1]. Endovascular treatment consists of filling the aneurysm bulge with platinum coils to cause a thrombotic reaction that seals the pouch. The procedure is conducted under fluoroscopic imagery that displays tools movement inside the patient. Endovascular coiling is complex in terms of vascular navigation of micro-catheters and guide wires when reaching the aneurysm site. The skull bone is also dense and it reduces interventional tools view to a minimum. Fluoroscopic imagery is constantly used throughout the intervention and is calibrated to minimize radiation exposure. This results in images with low resolution and low contrast. View planes are limited by collision avoidance and angle limits due to C-arms mounted source-detector configuration. The physician's ideal working plane of view might not be possible to setup because of system limits. A working plane is chosen for its best view of the incoming coil with no overlay of the aneurysm with its feeding blood vessel. The second plane is used to display an approximate side view of the aneurysm to improve the spatial understanding of the tools in motion and the coils' deployment inside the bulge.

Recent research efforts have been focused on the development of a three dimensional display of tools during endovascular interventions to help interventional neuroradiologists. Segmented tools are preferably shown inside a 3D reconstruction of the vascular tree acquired at the beginning of the intervention with a C-arm rotational scan of the blood vessel filled with contrast agent. The endovascular navigation could then be done without further use of contrast agent. A 3D representation of the scene could also help generate a plane of view normally impossible to show. The first and most studied endovascular tool for 3D reconstruction is the guide wire because it may be difficult for the interventional neuroradiologist to understand the underlaying vascular system without seeing it in real-time. The first application of guide wire segmentation reported by Palti-Wasserman et al. was for coronary arteries navigation during angioplasty [2]. The radiographic images are filtered in a preprocess stage to enhance the linear structure of the guide wire. The wire is then tracked in each frame with a second-degree polynomial using the Hough transform. This semi-automatic algorithm is confined to a small active window to reduce calculation time and enhance tracking performance. The digitized tool is then projected back on the live radiographic feed. Palti-Wasserman's algorithm was tested on synthetic images and a limited number of *in vivo* images with a good success rate. Bender developed image processing algorithms to follow catheters inside a patient's chest in fluoroscopic images during diagnosis and therapy [3]. The catheter edge is enhanced with the local gradient magnitude and it is repositioned from control points on each frame using an iterative process. However, the start points and directions are manually selected. The method of tool tracking from previously identified locations was also studied by Baert, van Walsum et al. [4, 5, 6]. A single guide wire is tracked on both radiographic projection and reconstructed in 3D inside the previously acquired vascular tree. The image processing on each view is done in two stages: first a rough estimate of displacement is calculated using template matching algorithms, and then a snake representation of the guide is fitted using optimization of local energy (geometry and image intensity). The image processes needed for guide repositioning are image subtraction and anisotropic filtering based on Hessian eigenvalues. Experiments were done on phantoms and on a limited number of *in vivo* images with good results. Baert's guide wire tracking technique failed with certain types of movement because it was trapped on non-moving curves. The process was then patched with a second iterative algorithm for endpoint detection. The overall calculation time is demanding; a single frame process took 5 seconds in the experiments. The guide wire must also be manually identi-

fied on the first frame. Bredno developed a live guide wire segmentation on single plane fluoroscopy during cathlab intervention [7]. The 2D vascular view is extracted offline from contrast enhanced angiographic image sequences. The guide wire is then segmented in real-time on each frame using frequency filters and gradient based enhancement algorithms. The wire is displayed on the vascular projection with a matching of elongated structures. This computerized tool has less clinical assistance value since the tool and the vessel are not precisely matched. Zarkh published research objectives and a few results for guide wire visualization inside the CardiOp-B software [8]. The guide wire segmentation and tracking is based on the analysis of paired tips. On each frame, possible endpoint tips are paired and compared to the previous frame for possible match. This tracking process eliminates artifacts in time if they are not repetitive. Since endpoints are paired in small regions of interest, only small guide wires are traceable.

The goal of tool tracking in real-time is feasible if endovascular tools are initially located. Once initialization is performed, the subsequent algorithms based on tool tracking are more computationally efficient than solo continuous segmentation in every single frame. No existing work has demonstrated acceptable performance in initial guide wire detection and segmentation in fluoroscopic images (low contrast and resolution). Segmentation processes are generally developed for the extraction of anatomical structures on medical images. An interesting example is the segmentation of blood vessels which are line-like structures, closely resembling guide wires in some situation. Thus line-like enhancement filters used for vessel segmentation are relevant for the application of endovascular tool detection. Many authors [9, 10, 11, 12, 13] used filters based on eigenvalues of the Hessian matrix to enhance vessels or bronchi on MRI, CT and DSA images. Those methods perform precise enhancements of curvilinear structures based on width and height. In other works, Poli and Vali applied shifted Gaussian filters directionally to reconstruct skeleton shaped vascular structures via hysteresis thresholding [14]. In this case, multiple filter scans are needed to highlight all edge directions.

In this paper a novel guide wire segmentation algorithm based on existing vessel enhancement techniques is presented. The proposed algorithm is suited for different kinds of guide wires and for coils of variable length, shape and radiopacity. The algorithm can segment more than one tool in the same image with crosspoints present on the planar view. This particular situation was never addressed in existing works. The segmentation technique is composed of an Hessian-based line-like enhancement algorithm which is used for low thresholding. Line candidates are then broken at crosspoints and measured to eliminate artifacts. The remaining line segments are connected in the planar view using alignment criterion. The algorithm was then tested on the first image of *in vivo* biplanar fluoroscopic sequences from endovascular interventions on patients with cerebral aneurysms.

2. METHODS

The segmentation algorithm presented in this paper is the first component of a larger program. This program starts with an initialization process consisting of an automatic tool segmentation on biplanar fluoroscopic images. This part is not performed in real-time and can last a few seconds. The second component is the real-time tracking of endovascular tools from live fluoroscopic views, also studied by many authors [2, 3, 4]. This second part must be light for fast computation. The third component of the program is a control agent that detects the arrival of a new tool inside the covered volume or the departure of an existing tool from the same volume. The program architecture is based on a virtual map of the endovascular tools inside the volume of sight. This virtual map is composed of the database of the current tools' positions. The initialization process can be triggered manually for any reason during the intervention. This gives the tracking process a reset of the virtual map, thus ensuring robust performance in the event of a major patient movement or tool tracking failure.

This paper presents an automatic tool segmentation on biplanar fluoroscopic images, which forms the initialization process of the program. Specifically, line-like tools are segmented. They can be guide wires or embolization coils.

2.1. Wire Enhancement

At first line-like structures are enhanced on each individual view using a filter based on the eigenvalues of the Hessian matrix. These algorithms normally used for vascular segmentation are perfectly suited for endovascular tools extraction. Frangi [11] proposed a compact equation of two or three eigenvalues of Hessian matrices (2D or 3D images) with two adjustable parameters. This formulation was also used by Olabarriaga [12], Cañero [13] and Bredno [7]. The 2D form is presented in Equation 1.

$$w(s) = \begin{cases} 0 & \text{if } \lambda_1 > 0, \\ \exp\left(\frac{-\mathcal{R}_B^2}{2\beta_1^2}\right)\left(1 - \exp\left(\frac{-S^2}{2\beta_2^2}\right)\right) & \text{else} \end{cases} \quad (1)$$

where $w(s)$ is the wire enhancement result at scale s, λ_1 and λ_2 are eigenvalues of the Hessian matrix, $\mathcal{R}_B$ is the blob-like structure measure, S is the second-order structureness measure proposed by Frobenius' matrix norm and β_1 and β_2 are ratios controlling the sensitivity of $\mathcal{R}_B$ and S. These measures are described as functions of eigenvalues in Equation 2 and 3.

$$\mathcal{R}_B = \left|\frac{\lambda_2}{\lambda_1}\right| \quad (2)$$

$$S = \sqrt{\lambda_1^2 + \lambda_2^2} \quad (3)$$

The sensitivity ratios β_1 and β_2 must be calibrated to the wire width. Since the source - detector distance on C-arms is adjustable and the image processing unit is capable of digital zoom, the pixel measurement may change. The processed image must be resized to a fixed pixel size measurement or ratios must be tuned to each specific view dimensions. The wire enhancement value will be proportional to the image contrast, i.e. it will be proportional to the radiopacity as compared to the background of bones and soft tissues.

2.2. Line Segments Measure and Connection

Line segments are extracted from the wire enhancement image $w(s)$ by applying a simple threshold based on the image mean and standard deviation. A hysteresis threshold is not recommended because it could reject partially less visible wire segments. Measurements of width and intensity variations with the background are taken along each line segment as illustrated in Fig.1. Since the pixel size is known, the expected wire width in pixel is also known. A rejection criteria is constructed upon an expected mean and standard deviation of the wire's width along the line segment. Artifacts tend to have variable and uneven width. The wire intensity with the surrounding background also indicates the local radiopacity. This measure is variable along the wire segment since its local angle to the plane of view

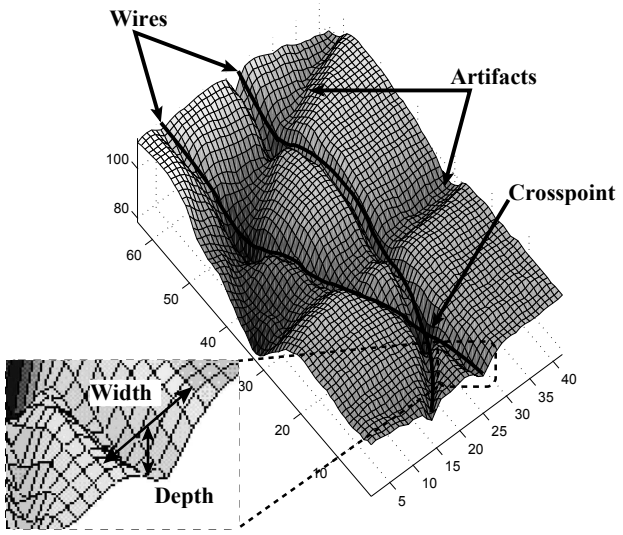


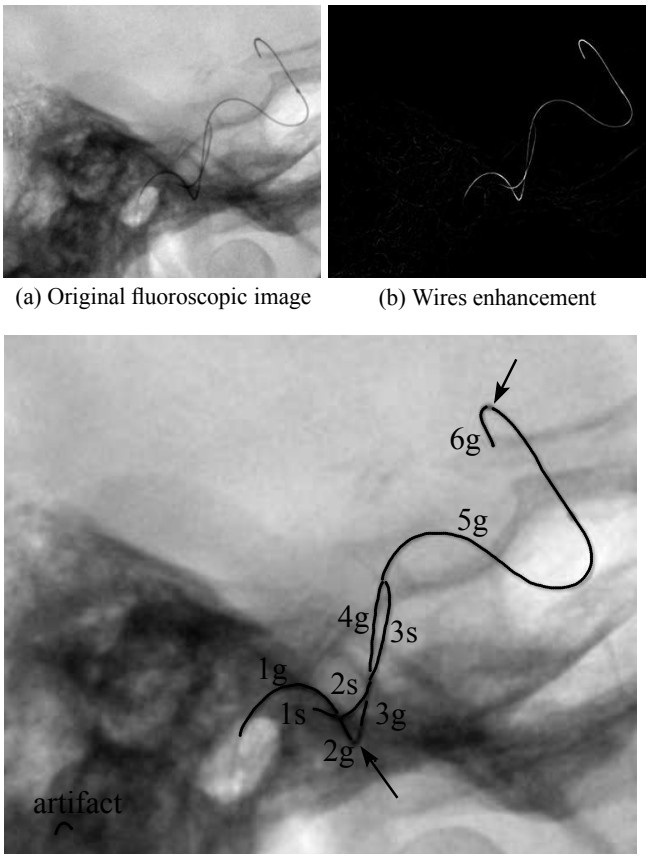
Fig. 1. Example of wire intensity effect on the background.

may change. But this variation is relatively smooth and can also become a rejection criteria. Local peaks in intensity and/or width may also indicate a crosspoint or an overlapping catheter marker. The crosspoint indication is useful to confirm certain 3D line segment connections (Fig. 1).

Line candidates extracted and retained from both fluoroscopic views are drawn on 2D images. The spatial projection to planar acquisition often causes crossings between different tools or even from a single tool. The extracted lines are broken on those crosspoints to sort them out. A connection operation based on tool tips alignment is performed to reconstruct the tools separately. The planar alignment criterion are the line segment candidate tips' distance, their planar angle resemblance and their individual planar angle resemblance with the virtual connecting line. The later criteria is useful to avoid false connections of misaligned but close tips. The four criterion are summed with adjusted ratios for all line tips' possible connections in proximity. The final connection acceptance is based on the selection of the best result from the planar summed criterion.

3. EXPERIMENTS

This initialization algorithm was tested on a large database of *in vivo* fluoroscopic image sequences. 21 different interventions were studied resulting in 98 saved biplanar sequences of guide wires. A biplanar imaging intensifier Axiom Artis BA by Siemens was used. The fluoroscopic frame rate was set at 15 images per second to reduce radiation exposure to the patient. Each sequence has a maximum of 300 consecutive images from the last 20 or less seconds of fluoroscopic viewing. Interventional fluoroscopic images were saved anonymously with approval from CHUM Notre-Dame Hospital's and École de technologie supérieure's ethics committees. An example of a single planar image process is shown in Fig. 2: where (a) is the original fluoroscopic image, (b) is the wire enhancement result and (c) is the threshold line segments. There are 10 line segments: 6 are on the long guide wire "g", 3 are on the small guide wire "s" and 1 is an artifact. Spatial connections successfully re-



(a) Original fluoroscopic image (b) Wires enhancement

(c) Line segments

Fig. 2. Example of wire segmentation.

constructed guide wire "s" and failed between segments 2g and 3g and between segments 5g and 6g because of wide angle matching (indicated with arrows), leaving guide wire "g" in 3 pieces. The remaining artifact can be easily removed after the connection operation by removing small remaining line segments. Overall results of the 98 tested sequences are summarized in table 1.

Out of the 61 sequences with a single guide wire present, 51 were successfully segmented. The other 37 sequences had 2 guide wires, half of it with one or more crossings as shown in Fig. 2. The major causes of failed connections are wide angles along wires or at crosspoints. The remaining causes are from a low contrast guide wire, from a viewing interference with the breathing tube and from multiple crossings overlay of the 2 guide wires. Only 2 guide wires out of the 135 segmented wires were wrongly connected because of crossing overlay. One of these cases is shown in Fig. 3.

4. DISCUSSION AND CONCLUSION

Existing studies on guide wire segmentation and tracking in fluoroscopic images is restricted to single device detection without the presence of crosspoint projection. The tools must also be initially manually identified. A 3D representation of the tools used in endovascular intervention is clinically useful only if projections that are currently difficult to obtain can be successfully displayed. This paper presented a new guide wire segmentation algorithm based on

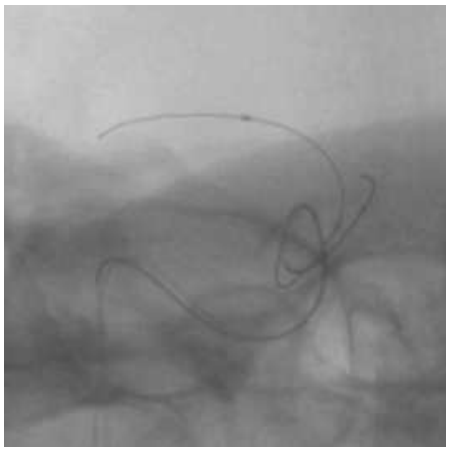


Fig. 3. Multiple crossings overlay example.

	2 guides	1 guide
Total sequences	37	61
Segmentation		
1 guide successfully segmented	13	51
2 guides successfully segmented	20	-
1 guide partially segmented	12	9
2 guides partially segmented	4	-
Failed segmentation (false connection)	1	1
Causes of partial or false segmentation		
Low contrast	-	2
Wide angle along wire	11	6
Wide crossing angle	5	2
Visual interference with other medical instrument	2	-
Multiple crossings overlay	4	-

Table 1. Guide wires segmentation results.

existing vessel enhancement formulas combined with a connection operation to fully extract multiple guide wires separately. Experiments were conducted on numerous in vivo fluoroscopic images with a high success ratio. The connection operation failed when the angle along a wire or at a crosspoint was wide. Work is currently underway to solve the 2D projection view limitations by representing the remaining line segments in a 3D biplanar reconstruction. The segments could be connected in space using a similar connection operation algorithm applied to 3D environment. This spatial representation would also eliminate the wide angle effect caused in 2D projection.

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